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The paediatric airway: Basic principles and current developments

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REVIEW ARTICLE

The paediatric airway

Basic principles and current developments

Alexander R. Schmidt, Markus Weiss and Thomas Engelhardt

Perioperative airway problems frequently result in significant morbidity and mortality in children. Therefore, proficiency in airway management is one of the most important key elements in the safe conduct of paediatric anaesthesia. This review includes important anatomical and physiological aspects of the paediatric airway, challenges encountered, and their management with commonly available resources. The importance of early recognition and treatment of anatomical or functional airway obstruction using locally adapted algorithms is highlighted. Children deemed at risk of aspiration require a controlled rapid sequence induction with sufficiently deep anaesthesia, confirmed complete muscle paralysis and intermittent ventilation prior to tracheal intubation. The benefits of a supraglottic airway device and a cuffed tracheal tube in paediatric airway management are discussed. The primary goal of mastering the paediatric airway is to ensure oxygenation and ventilation. This requires intricate knowledge, regular practice and experience.

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Introduction

Proficiency in airway management is one of the most important key elements in the safe conduct of paediatric anaesthesia. The understanding of fundamental concepts and use of local resources and algorithms is essential to reduce airway related morbidity and mortality in children. The following review summarises basic principles and current developments relating to the paediatric airway and its management.

The 'growing up' of the airway

Anatomical considerations

The paediatric airway undergoes considerable changes from birth to adulthood. These changes affect the development of the skull, oral cavity, larynx and trachea. The head is large relative to the body in infants and young children. Facial structures are small when compared with the neurocranium in the neonate because of the absence of the paranasal sinuses.[1] The oral cavity is small at birth and increases in the first year of life due to substantial growth of the mandible and teeth. The neonatal tongue has a flat dorsal surface, minimal lateral mobility and appears large in the small oral cavity.[2]

Neonatal laryngeal and tracheal structures are of particular interest to the anaesthetist.

The larynx appears more anterior during direct laryngoscopy but is loosely embedded in the surrounding structures when compared with adults. It can be moved easily by external manipulation into a position where direct laryngoscopic intubation is possible. The epiglottis is long, narrow and frequently U- or Ω-shaped, obscuring ('flopping') the glottic view on direct laryngoscopy if not lifted up by the laryngoscope blade. The glottis is higher in relation to the spine in neonates (C2/C3) and descends to its usual position at C5 after 2 years. The vocal cords are shorter in the neonate and comprise about 50% of the anterior glottis in contrast to two-thirds in an older child.

The neonatal larynx is conically shaped and approximately cylindrical in an older child. The larynx is thought to be widest at the supraglottic and narrowest at the subglottic level, although this view has been challenged in MRI studies indicating that the narrowest part may be at the glottis.[3] However, the cricoid ring is functionally the narrowest part of the neonatal airway, with an ellipsoid shape and a mucosal layer, which is highly susceptible to trauma. Air leakage bypassing an uncuffed tracheal tube at this level does not guarantee avoidance of pressure points and subsequent oedema.[4]

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The small internal tracheal diameter leads to a significant increase in airway resistance and this is exaggerated following mucosal injury. Tracheal length is related to the child's age and height, not to body weight.[5–7] Changes in head position during surgery may lead to displacement of the tracheal tube and the position of the tube requires reevaluation after repositioning of the head.[8–10] Verification of the position of the tracheal tube by clinical (chest movements, auscultation) or alternative means (chest radiograph, fluoroscopy, ultrasound or bronchoscopy) is recommended.

Physiological considerations

The age-dependent descent of the laryngeal structures is considered essential in the transition from obligatory nasal to oral breathing. The direct consequence is the separation of the epiglottis and soft palate.

The paediatric airway cannot be discussed without considering the very low functional residual capacity in young children. This, together with the higher oxygen demand, increased carbon dioxide production and increased closing capacity, results in a very low tolerance of apnoea, which rapidly leads to significant hypoxaemia and respiratory acidosis. Even optimal preoxygenation does not result in a sufficiently long 'safety period' to prevent desaturation following even short periods of apnoea. The younger the child, the less time there is.[11,12]

The laryngeal reflexes are among the most powerful protective reflexes in humans and are designed to prevent pulmonary aspiration. These are functional reflexes. The larynx is innervated by the recurrent laryngeal nerve and the external and internal branches of the superior laryngeal nerves. The recurrent laryngeal nerve supplies the afferent innervation of the subglottic part of the larynx and all muscles with the exception of the cricothyroid muscle. The larynx is relatively insensitive to inhaled irritants but very sensitive to mechanical or chemical stimulation induced by liquids or solids.[13] 'True' or 'complete' laryngospasm is defined as complete closure of the larynx through external stimuli. This is in contrast to glottic spasm or 'partial' laryngospasm, which is the strong approximation of the vocal cords only. The latter leaves a small lumen at the posterior commissure, allowing minimal oxygenation.[14] In complete laryngospasm, there is chest movement but with silence, with no movement of the reservoir bag and with no ventilation possible using a face mask. In partial laryngospasm, there is chest movement, but there is a stridulous noise with a mismatch between the patient's respiratory effort and the small amount of movement of the reservoir bag.[14]

Laryngospasm must be also be differentiated from postextubation stridor, commonly due to trauma of the paediatric airway and mucosal injury with subsequent oedema.

'Growing pains' of the airway

Known abnormalities of the paediatric airway represent a significant challenge to the paediatric anaesthetist.[15,16] Some abnormalities improve with age (such as Pierre Robin sequence, Goldenhar syndrome), whereas others deteriorate (such as Treacher Collins syndrome, Apert syndrome).[17] However, many syndromes have not only an isolated airway problem but also associated cardiac, neurological, metabolic or endocrine anomalies.

Paediatric airway and anaesthesia: the challenges

Routine airway management in paediatric patients is normally easy in experienced hands. However, perioperative airway problems occur frequently in children and may result in prolonged hypoxaemia, cardiac arrest and death.[18–20] The reported airway related mortality approaches zero in some specialised paediatric centres[21] but is likely to be underestimated in other areas such as emergency departments and ICUs.[22] It is to be noted that the long-term developmental consequences of perioperative hypoxaemia are still poorly understood and investigated.

Problems with the paediatric airway can be classified into three groups: the anatomically/physiologically 'normal'; the 'impaired normal' (previously 'normal' but acutely altered due to trauma, infection, swelling, burns and so on); and the 'known abnormal' (congenital abnormalities and syndromes).

All of the anatomical problems or difficulties may be accompanied by functional problems (Table 1).[23] A structured approach simplifies management.

'Normal', 'impaired' and 'abnormal'

The clear distinction between 'normal', 'impaired normal' and 'known abnormal' allows the nonspecialist anaesthetist to determine an appropriate approach to the child requiring anaesthesia services (Table 2).

The vast majority of children who require anaesthesia are healthy, with normal airway anatomy and physiology. Nonspecialist paediatric anaesthetists commonly provide the anaesthesia care for these children. However, airway

Table 1 Causes of unexpected face mask ventilation problems

Anatomical airway obstruction	Functional airway obstruction
Inadequate head positioning	Upper airway
Poor face mask technique	Inadequate anaesthesia
Large adenoids, tonsils, obesity	Laryngospasm
Foreign body, gastric content, blood	Opioid-induced glottic closure
	Lower airway
	Opioid-induced muscle rigidity
	Bronchospasm
	Alveolar collapse (apnoea, tracheal suctioning)
	Overinflated stomach

Modified from [23].

Table 2 Simple classification of the paediatric airway

Normal paediatric airway – 'Unexpected'	Time: critical
	Place: anywhere
	Who: anyone
	Comment: established paediatric airway algorithm essential
Impaired normal paediatric airway – 'Suspected'	Time: urgent
	Place: anywhere, consider transfer to specialist centre
	Who: expertise required, consider ENT support
	Comment: anaesthetic intervention dictated by rate of deterioration
Known abnormal paediatric airway – 'Expected'	Time: normally elective, planning essential
	Place: paediatric specialist centres only
	Who: specialist expertise required, ENT support essential
	Comment: Exception life/limb-saving surgery

The vast majority of children have a normal airway. The known difficult paediatric airway is the domain of the experienced paediatric anaesthetist.

problems do occur and require a simple, intuitive, algorithm-based approach.[24]

The impaired normal paediatric airway requires experience and skill. Previously healthy children with no signs or previous history of a difficult airway may present in respiratory distress due to an acute illness. The gravity of the underlying disease (infectious, allergic swelling, trauma or burn) and speed of deterioration dictate the anaesthetic approach. Resuscitation, organisation and preparation of appropriate staff, location and equipment should be arranged if the condition of the child allows. Surgical (ENT) support is required if the anaesthetist is not experienced enough or has doubts about the ability to oxygenate and ventilate.

The child with a 'known abnormal' airway is rare and normally presents for elective surgery. This scenario is a domain of the specialist paediatric anaesthetist and these children should be cared for in specialist paediatric units. Immediate ENT support is essential if there are doubts about the ability to oxygenate. Only life-saving or limb-saving surgery should be undertaken in peripheral centres and transfer/retrieval must be organised as soon as possible. Maintenance of spontaneous ventilation and the use of a laryngeal mask airway or nasopharyngeal tube is advisable in these children.

Anatomical or functional airway obstruction

In addition to the approach outlined above, any child can experience anatomical or functional airway problems in the perioperative period.

Anatomical airway obstructions are caused by poor technique such as incorrect use of the face mask, suboptimal positioning of the patient's head, mandible and upper thorax, and failure to recognise airway obstruction caused by large adenoids and tonsils. A simple triple airway manoeuvre and the use of an appropriately sized oropharyngeal airway usually overcome these problems. Mechanical obstruction due to secretions, blood, regurgitation or foreign bodies requires removal through suctioning under direct laryngoscopic vision. Gastric distension leads to ventilation and oxygenation difficulties in children and requires decompression by orogastric suctioning, possibly even during mask ventilation. Unexpected subglottic or tracheal mechanical obstruction by inhaled foreign bodies can usually be overcome by inserting a smaller tracheal tube. Peripheral lung collapse in small neonates and small infants after prolonged and/or failed tracheal intubation requires careful lung recruitment in order to restore oxygenation.[25,26] If no mechanical obstruction is detected during direct laryngoscopy and the trachea cannot be intubated, a supraglottic airway device must be inserted in order to overcome any anatomical supraglottic airway problems and to ensure oxygenation.[23]

Functional upper airway obstruction is common in children and may be caused by insufficient depth of anaesthesia, laryngospasm or opioid-induced glottic closure. Functional lower airway obstruction is less common and can be caused by bronchospasm or opioid-induced muscle rigidity of the thoracic wall. Treatment options in the child without comorbidities include the administration of additional hypnotics, muscle relaxation and epinephrine. These functional airway obstructions and their treatments in a 'cannot ventilate' situation have recently been highlighted in an editorial.[27]

Difficulties and emergencies

The primary goal of paediatric airway management is to ensure oxygenation and ventilation. A good basic bag/mask technique is the cornerstone for success. This requires regular (daily) practice and dedicated teaching.

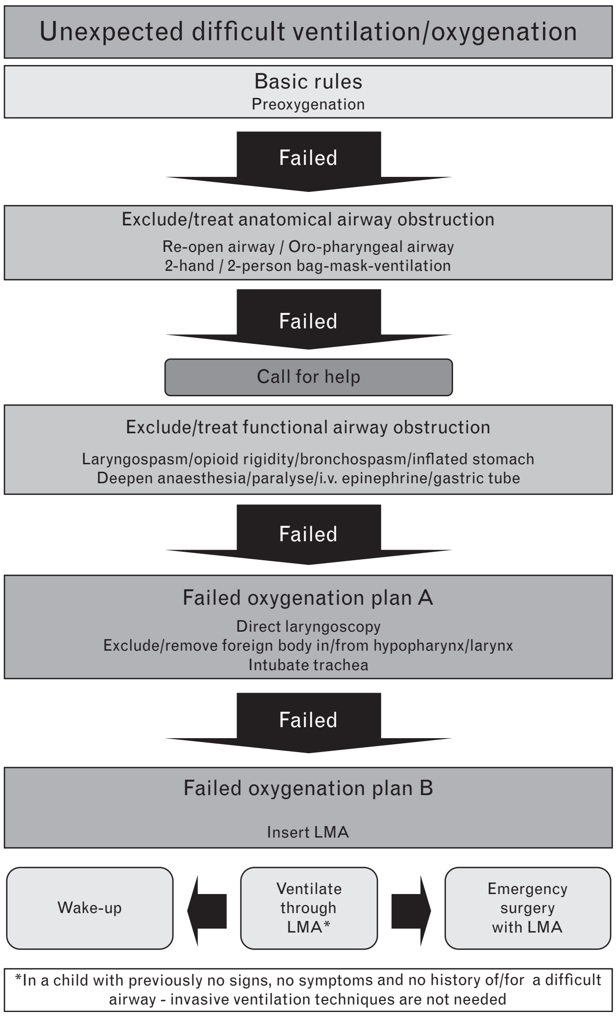
Impossible face mask ventilation in the otherwise normal child in the hands of experienced paediatric anaesthetists probably does not exist. However, there are only abstract data to support this statement and peer-reviewed publication is awaited.[28,29]

Anatomical or functional airway obstruction requires a simple, forward-only, easy to memorise algorithm in order to avoid tissue hypoxia (Fig. 1).

Tracheal intubation is a skill mastered by anaesthetists and often copied or attempted by other physicians. The primary goal must be prevention of hypoxaemia, not tracheal intubation.

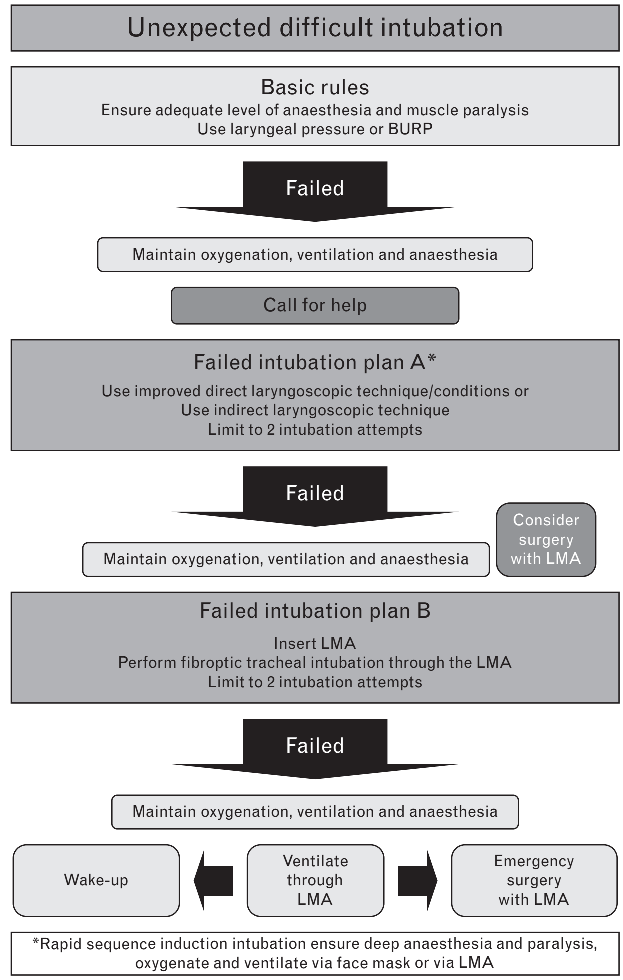
Difficult laryngoscopy (Cormack and Lehane grade 3 or 4) is generally less common in children than in adults. Risk groups for difficult laryngoscopy are age (less than

Fig. 1



Suggested algorithm to overcome unexpected difficult oxygenation or ventilation problems in otherwise normal children. Anatomical and functional airway obstructions require a simple, forward-only and easy-to-memorise algorithm in order to avoid hypoxaemia. Adapted from [24] LMA, laryngeal mask airway.

Fig. 2



Suggested algorithm for unexpected difficult tracheal intubation in children. A simple, 'open-box' approach using the best local facilities and expertise is indicated. If unable to ventilate via tracheal tube, exclude Displacement, Obstruction, Pneumothorax, Equipment failure and overinflated Stomach (DOPES). Adapted from [24] BURP, backward, upward and rightward pressure on the thyroid cartilage; LMA, laryngeal mask airway.

1 year) and craniofacial dysmorphism. In addition, American Society of Anesthesiologists' physical status greater than 3, Mallampati score greater than 3, extremes of BMI and specific types of surgery (cardiac and maxillofacial) are associated with difficult laryngoscopy.[30]

Tracheal intubation also requires good basic technique, regular practice and dedicated teaching. Tracheal intubation attempts must be limited because the paediatric airway is susceptible to trauma and swelling. A simple, 'open-box' algorithm approach using the best local facilities and expertise is indicated (Fig. 2). A locally accepted alternative glottic visualisation device (e.g. optical stilette), endoscopic laryngoscope or videolaryngoscope should be available if conventional direct laryngoscopy fails (Plan A).[24,31] Fibreoptic-assisted tracheal intubation via the laryngeal mask airway or another appropriate supraglottic airway device is a simple and well tolerated method for tracheal intubation in children (Plan B).[32–35]

Abandoning conventional direct laryngoscopy in favour of various types of videolaryngoscopy for all patients cannot be recommended currently because familiar equipment may not always be available or suitable for all situations. Proficiency in direct laryngoscopy and a good basic face mask technique remain the foundation of airway management in children.

Classic rapid sequence induction and intubation is not suitable for younger children because this technique does not include intermittent ventilation and oxygenation. This results in unnecessary and preventable hypoxaemia, bradycardia, hypotension, trauma and stress.[36] A ‘controlled’ induction with deep anaesthesia, profound muscle relaxation and gentle intermittent face mask ventilation is required to overcome these problems.[37–39]

The ‘cannot intubate, cannot oxygenate’ (CICV) situation is the worst-case scenario and rare in paediatric anaesthesia. Early recognition and management based on the principles above prevent its occurrence in otherwise healthy children. Treatment options are either surgical or cannula tracheotomy. However, before any of these major invasive techniques is employed in an emergency, functional airway obstruction must be excluded and the child fully paralysed.[22,27] This break in traditional thinking is supported by the recent fourth National Audit Project (NAP4) report[40] and the fact that an anaesthetised paediatric hypoxic brain does not re-open the upper airway or restart ventilation.

An experienced ENT surgeon may be of assistance in elective and anticipated situations. Rigid bronchoscopy is a useful life-saving technique but instantly available in only a few centres. Limited data are available currently to recommend either technique. Cannula tracheotomy is only partially successful in adults[18] and has a success rate of approximately two out of three attempts in rabbit or pig trachea models not truly representative of anatomical tissue conditions in infants and smaller children.[41,42] The experimental pig study[41] reported a much higher success rate for surgical tracheotomy of 95%. Preliminary and unpublished results of a recent Association of Paediatric Anaesthetists’ survey reviewed intervention for the CICV scenario in 75 patients (48 <1 year, 17 aged 1 to 5 years and 10 children older than 5 years). Remarkably, the results also suggest that cannula tracheotomy was successful in 13 out of 16 (69%), surgical cricothyroidotomy in 31 out of 35 (94%) and 100% (26/26) using rigid bronchoscopy. Details of this survey, including details of morbidity during these invasive manoeuvres, remain to be reported. However, when this information is available, it may be possible to provide robust recommendations for management of this rare event in paediatric anaesthesia (Association of Paediatric Anaesthetists of Great Britain and Ireland survey 2012, unpublished data).

Things that may make our lives easier

Prediction of airway difficulty and then taking the appropriate action can make the difference between a ‘good’ and a ‘bad’ outcome in anaesthesia. However, there is no single universally accepted preoperative test or investigation in children that reliably informs the anaesthetist. Preoperative airway assessment includes mouth opening, dentition, soft tissue swellings and abnormalities, particularly those of the ear and mandible, thyromental distance, craniofacial abnormalities including asymmetries and flexion/extension of the neck.

Clinical examination identifies children at high risk of anatomical, mechanical or functional airway obstruction (e.g. bronchial hyperreactivity, respiratory infections, asthma and passive smoking).

The imaging armamentarium available to identify fixed or dynamic abnormalities (or a combination of both) to anaesthetists has been reviewed recently.[43] The performance of most imaging techniques is beyond routine clinical anaesthetic practice, but ultrasound has become increasingly popular not only for regional anaesthesia or vascular access but also for the airway. Ultrasound may also be used to identify correct tracheal tube placement or predict correct tracheal tube size, although it has yet to be established in routine clinical practice.[44–46]

The laryngeal mask airway has revolutionised anaesthesia, including paediatric anaesthesia. Developments of second generation devices in adults (including a gastric channel) have also reached this subspeciality. There appears to be no clear superiority of one device over another in clinical practice.[47–49] However, the supraglottic airway device with the longest record of efficacy remains the LMA Classic.[50]

Supraglottic airway devices are particularly useful to overcome congenital abnormalities and serve as a conduit for fibreoptic intubation.[32–34,51,52] They are not suitable to overcome functional airway problems or for use with desflurane in spontaneously breathing patients,[24,53] and are unsuitable for mechanical airway obstruction (e.g. as a result of foreign bodies or soiled upper airways).

Modern cuffed tracheal tubes are now accepted in paediatric anaesthesia as being well tolerated and efficient.[54–56] It is essential to note that continuous cuff pressure monitoring is mandatory throughout the use of cuffed tracheal tubes in children to avoid unnecessarily high pressures on the tracheal mucosa.[57] Long-term surveillance data indicate that there are no relevant airway problems resulting from short-term intubation.[58] Cuffed tubes have a lower rate of sore throat, postoperative stridor and perioperative laryngospasm.[53] The debate over cuffed versus uncuffed tracheal tubes in paediatric anaesthesia should end, with uncuffed tracheal tubes reserved for specific indications such as intentional bronchial intubation for neonatal thoracic surgery and lung isolation.[59]

Dedicated airway trolleys are available in more than 90% of departments where children are anaesthetised.[60] Ideally, these are adapted to locally accepted difficult airway algorithms.[24] It is concerning, however, that not all dedicated trolleys/carts are regularly maintained and checked, and some may have essential equipment missing. Establishment of protocols for equipping and maintaining airway trolleys, and regular training in their use, appear to represent common sense and should become mandatory.[60]

This review can address only a limited number of generalised aspects of the paediatric airway without detailed discussion of congenital glottic abnormalities, subglottic anomalies and anterior mediastinal mass syndromes.

Conclusion

The good news is that, with understanding of fundamental concepts, appropriate use of precious resources and establishment of locally adapted algorithms, perioperative hypoxaemia in children is preventable and immediately treatable. However, the bad news is that hypoxaemia and tissue hypoxia still occur and remain a significant factor in preventable morbidity and mortality in children. The challenge remains to eliminate avoidable tissue hypoxia in children through continuing training and education.

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